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13. ABSTRACT (Maximum 200 words) <p>We prepared the first systematic survey of seafloor sediment type in the Red Sea, Gulf of Aqaba, Gulf of Suez, and Gulf of Oman. We mapped bottom annotations on archived navigation charts, unpublished surveys, descriptions published in journals, and observations from NGDC. The maps show the affects of laterally varying rates of tectonic uplift, composition of sedimentary rocks exposed on-land, reworking by currents, distance offshore, biogenic productivity, and reef building. Shelf sediments in the southern Red Sea and off southern Oman are mostly coarse-grained carbonate debris produced by coral reefs and shell-forming macro-organisms and fine-grain carbonate sand and mud from algae and foraminifera. Bottom currents driven by tides, winds, and density differences sort and redistribute sediment, break blocks of reefal debris down, and expose hardgrounds. The shorelines of the Gulfs of Suez and Aqaba are tectonically rising producing steep exposures of soft sedimentary strata and Neogene volcanic deposits. Eroded sedimentary and volcanic debris is much more common here than in the Red Sea. Along the north and east shore of the Gulf of Oman, muds are the most common sediment type, while sands of both terrigenous and biogenic origin are found in water depths less than 10 m.</p>				
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## **Final Report to ONR**

### **Seafloor sediment studies in the Middle East**

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#### **LONG TERM GOALS**

The distribution of sediment types on the seafloor reflects the relative supply rates of biogenic and terigenous sediment types and the effects of physical, chemical, and biologic processes in the upper sediment layer after deposition. Our long-term goal is to improve our understanding of the balance of factors that control the composition of shallow water sediments in arid basins of the Middle East.

#### **OBJECTIVE**

The primary objective of this project is to determine the nature and spatial variability of sediment composition at shallow water depths in marine basins of the Middle East: the Red Sea, Gulf of Suez, Gulf of Aqaba, and the Gulf of Oman. The project was undertaken as part of a compilation of sediment types by Navoceano for mine warfare purposes.

#### **APPROACH**

For this study we used publicly available data. We digitized locations and sediment compositions from literature sources and compiled observations from the NGDC surface sediment core data base. We also obtained archived editions of navigation charts published before 1972 by the Hydrographic Office of the British Admiralty that show seafloor sediment type as bottom annotations. These data sets were merged, and sediment types were mapped. Classifications are primarily based on sediment texture, but composition is also considered

#### **WORK COMPLETED**

In early 1998, we prepared maps for the southern and northern Red Sea and for the Gulfs of Suez and Aqaba. We compiled data from NGDC and from an extended search of the published literature. Correspondents in the Naval Historical Center, National Archives, Library of Congress, Israel, Saudi Arabia, and Egypt provided assistance. Bottom annotations made on old editions of British Admiralty bathymetry charts provided the most detail. The smallest scale charts covering the region were obtained by mail from the archives of the British Admiralty Hydrographic Office and from the US Naval Hydrographic Office archives during a visit to the National Archives at College Park, MD. The data on 21 bathymetry sheets were compiled with published and NGDC data, sediment types were mapped, and the 21 sheets were submitted to Navoceano in early June. Revised maps were submitted in mid-July. Sediment types for ten bathymetry sheets in the central Red sea were submitted to Navoceano in late October 1998. In November 1998, 15 charts were prepared for the Gulf of Oman from the approaches to Karachi in eastern Pakistan west along the Makran coasts of Pakistan and Iran, across the Oman-Iran continental shelf at the entrance to the Straits of Hormuz, and south along Oman to 20°11'N.

#### **RESULTS**

Shelf sediments in the southern Red Sea are mostly coarse-grained carbonate debris produced by coral reefs and shell-forming macro-organisms (eg. mollusks) and fine-grained carbonate sand and mud from coralline algae and foraminifera. Trace components of local igneous rock outcrops are also found. Bottom currents driven by tides, winds, and density differences are very important near the coastline, between coral reefs, and in the Straits of Bab-el-Mandeb. These currents sort and redistribute sediment, break blocks of reefal debris down

into finer grains, and expose hardground layers. The shorelines of the Gulfs of Suez and Aqaba are tectonically rising producing steep exposures of soft sedimentary strata and Neogene volcanic deposits. In these basins, eroded terrigenous sedimentary and volcanic debris is a much more common constituent of bottom sediment than in the Red Sea to the south. Current reworking is important only in the straits at the southern ends of the Gulfs where they join the Red Sea. Sediments are generally finer grained than in the southern Red Sea.

The Gulf of Oman is bounded on the north by the rapidly rising Makran range and on the east by delta of the Indus River, which drains the western end of the Himalayan Mountains. Unlike the Red Sea and the Gulfs north of the Red Sea, the Gulf of Oman is subject to the monsoon cycle bringing abundant rain to the Indian subcontinent during summer months. As a result, the shelf seafloor off eastern Pakistan and northwest India is predominantly composed of terrigenous fine sands and silts. Likewise, muds are the most common sediment type observed offshore along the Makran coast. In both regions, sands of both terrigenous and carbonate biogenic origin are found along the shore in water depths less than 10 m. Local outcrops of igneous rocks on the outer shelf of Pakistan near 24.1°-24.4°N and just offshore of the Hab River mouth (~24.8°N) contribute coarse sands and gravels. Strong tides and monsoon-driven currents rework the Pakistani shelf, particularly in water depths of less than 25 m, and disperse sediments several tens of kilometers from their shelf sources. Accumulation rates are much higher than in the Red Sea.

In western Pakistan and southernmost Iran, seaward propagating tectonic uplift is raising consolidated sediments deposited in shelf and slope environments during the last few million years. Rock outcrops on land are most often weakly cemented siltstone and mudstone. These rocks weather quickly and disaggregate completely below sea level, so that muds are often found within 1-2 nmi of steeply dipping coastlines. The climate is arid, but the rare rainstorm causes catastrophic flooding and massive transport to the shelf of fine-grained material. The seafloors of bays along the Makran coast are mostly silts and clays intermixed with sand and shell material. Significant tidal flushing is indicated by the presence of shell and sand in the middle shelf at distances of 10-15 nmi off the mouths of most bays and headlands. Terrigenous sand is the most common constituent within 1-2 nmi of the shore. On the middle and outer shelf, patches of rock and muddy sand extending over 2-5 nmi interrupt the mostly muddy seafloor. These regions are the next series of fault blocks being lifted up into the coast ranges.

The composition of seafloor sediments at the southern end of the Straits of Hormuz (entrance to the Arabian/Persian Gulf) is controlled by strong lateral gradients in the supply of terrigenous sediments and in near-bottom currents. Whereas large quantities of fine-grained muds and silts reach the Straits from rivers draining arid mountains in Iran, little sediment reaches the ocean from well-consolidated carbonate rocks forming the Musandam Peninsula in Oman. The eastern side of the Straits out to the shelf-edge is comprised of mud and sandy mud. Shell debris is common both as an add-mixture to the mud and as a distinct sediment type covering regions up to 2-3 nmi in width. The bathymetric channel from the Arabian Gulf runs down the Oman (west) side of the southern Straits of Hormuz. Density-driven bottom currents flow out of the Arabian Gulf in this channel, and tidal currents are accelerated as well. As a result of current scour, the sediments here are coarser. Non-biogenic sands, gravels, and shell debris are the most common sediment types. The rock formations forming the coast of the Musandam Peninsula are largely Cretaceous carbonates, and the near-shore sediment is detrital gravel and coarse sand which is carbonate in composition.

The Oman shelf to the south of the entrance to the Arabian Gulf narrows to 2-12 nmi. The sediments are largely biogenic carbonate in composition. South of 22°N the shelf widens gradually to >30 nmi, and the morphology and sediments resemble those of the Red Sea. The climate along the coast is arid and the tectonics are much more stable than those of the Makran, so little terrigenous material mixes with the debris from reefs and lagoons fringing the shoreline. Most of the shelf is covered with sand. Within one mile of the coast, coral and rock are commonly mixed in with the sand. At the shelf-edge, there is a transition from shelf sand to silt and mud on the continental slope.

## **IMPACT/APPLICATIONS**

These maps are the first systematic data base of sediment types in these regions. In the Gulf of Suez, the results differ significantly from published compilations. The effects of tectonics are clearly evident on composition of seafloor sediments in the northern end of the Red Sea. To the south tectonic uplift is less rapid and further from the coast, so there are fewer steeply dipping coastlines to erode. As a result of the lower relief and dry climate, little terrigenous debris reaches the shelf and most sediment has a biogenic origin. In the southern Red Sea, the sediments tend to be coarser, sediments are more likely to be reworked by tidal currents, the seafloor is harder, and there is more local micro-relief.

The Pakistani shelf north of the Indus River mouth is strongly affected by the high rates of mud supplied to the ocean on a seasonal basis. The seafloor is reworked by tidal and wind (monsoon) driven currents. The seafloor is generally soft and flat, but admixtures of sand may locally affect seafloor rigidity and acoustic properties. Off the Makran coast of Pakistan and Iran, soft mud is also the predominate feature. Here, mud and coarse shell debris mixtures occur across the shelf. In low concentrations, shells are unlikely to affect the bearing capacity of the mud but will profoundly affect the reflectivity of the seafloor. Detailed surveys by British survey vessels of the Iranian Makran shelf in the late-1970's indicate that two factors appear to increase the "softness" (or bearing capacity) of the seafloor: low proportions of sand and high rates of sedimentation. Boundaries between "soft" and "not soft" seafloor often cross textural boundaries. Assuming that the data marked on the British Admiralty charts are accurate, this suggests that sedimentation rate may be the key factor in determining the physical properties of the seafloor here.

On the shelf between Oman and Iran at the southern end of the Straits of Hormuz, the primary factors affecting seafloor sediment type is the composition of the rocks exposed on-shore and the east-west asymmetry in speed of bottom currents. Both side are equally arid. The Iranian mountains are comprised of fine-grained sedimentary rocks which erode easily producing fine-grained clastics at relatively high rates from river mouths, whereas the Oman mountains are largely comprised of well-cemented carbonates that erode slowly and produce lower rates of coarse material. There is a distinct boundary running north-south across the shelf between the two regimes that separates hard, coarse-grained, irregular seafloor to the west from softer, fine-grained, rapidly accumulating, topographically smoother seafloor to the east.

The shelf off Oman south of ~25°N more closely resembles that in the southern Red Sea. The seafloor is commonly hard, irregular, and slowly accumulating. The only exceptions may be the coastline seaward of subaral valleys and seasonal rivers where mud may be locally accumulating close to the shore.

## **TRANSITIONS**

The sediment types maps were compiled in cooperation with the mine warfare mapping project at NAVOCEANO (Code N5). The maps have been given to NAVOCEANO for digitizing and incorporation in their data bases.

## **RELATED PRODUCTS**

The search for hydrographic charts with bottom annotations revealed many data collected by the British Admiralty in key regions of the Arabian (Persian) Gulf that were previously unknown and have been incorporated in our studies of the sedimentation in the Gulf under other ONR grants.

## **PUBLICATIONS**

Funds from this project were used in the preparation and publication of one paper:

Uchupi, E., S.A. Swift, D.A. Ross, 1999, Late Quaternary stratigraphy, paleoclimatology and neotectonism of the Persian (Arabian) Gulf region, *Marine Geology*, 160, 1-23.